THE NATIONAL ADVANCED DRIVING SIMULATOR: POTENTIAL APPLICATIONS TO ITS AND AHS RESEARCH

Douglas A. Stall
TRW, Transportation Systems
One Space Park
MS R2/1020
Redondo Beach, CA 90278
310.813-4247
Fax 310.813-4522
e-mail dougstoll@smtp.rc.trw.com

Simon Bourne
Dynamic Research, Inc.
355 Van Ness Ave.
Torrance, CA 90501
310.212-5211
Fax 310.212-5046

January 15,1996

ABSTRACT

In announcing the new Operation Timesaver program in January of this year to the Transportation Research Board, DOT Secretary Frederico Pena stated: "I want 75 of our largest metropolitan areas with a complete Intelligent Transportation Infrastructure in 10 years."(l) The goal of this system is to reduce daily travel time by 15%. The upcoming deployment of various Intelligent Transportation Systems (ITS) and Automated Highway System (AI-IS) technologies will require major adjustments in the habits of drivers. Implementers of ITS technology must ensure that their systems are safe and lead to real improvements in traffic efficiency. These systems cannot cause excessive driver workload or remove his/her sense of "control" of the vehicle. A highly realistic driving simulator provides a powerful method of evaluating in-vehicle ITS technology in complex situations. Representative traffic scenarios can be examined safely with experimental repeatability, easy reconfigurability and excellent data collection capability. This paper describes the background and potential applications of the National Advanced Driving Simulator (NADS) to be developed by TRW for research supporting the objectives of ITS and AHS systems and product development. Simulator technology has advanced dramatically in the last few years in the areas of vehicle multi-body dynamics simulation. real-time computer performance, ultra-high fidelity visual displays and large motion drive systems, It is now technically and economically feasibie to build a dnving simulator that can recreate the sense and feel of driving. In a few years, the NADS will be available as a new tool for engineers to develop, evaluate and field advanced ITS and AHS products.

INTRODUCTION

The US Department of Transportation's National Highway Traffic Safety Administration (NHTSA) has embarked on a program to build the world's most sophisticated driving simulator, known as the National Advanced Driving Simulator (NADS). NADS will be a national research asset located at the University of Iowa's Oakdale Research Facility, and is planned to support three fundamental types of research: (2)

- Traffic safety and human factors investigations,
- Engineering trade-studies to support improved vehicle safety and quality, and
- New simulation technologies which could improve US economic competitiveness.

NHTSA will use NADS for safety and human factors research in a new capacity: as a partner with industry and highway development engineers to study the total driver/vehicle/traffic environment system with an eye to improving products. highway designs. and reducing the causes of accidents -- not just reducing fatalities. NHTSA's Office of Crash Avoidance Research (OCAR) plans to use the NADS to investigate driver behavior in complex and potentially dangerous scenarios. In fact. OCAR's research efforts support ITS objectives in five major thrusts: (2)

1. Build research tools and compile knowledge bases.
2. Identify promising crash avoidance opponunities.
3. Demonstrate proof of concepts for crash avoidance and mitigation.
4. Facilitate Commercial Development.
5. Support the safety assessment of other ITS concepts.

The first thrust includes programs to develop portable data acquisition systems for collecting real-time driver and vehicle performance, quantifying specific driver behavior patterns in normal traffic, developing a collision avoidance and driver workload framework, and research into the health hazards of anti-collision technologies. It also supports the definition of automotive computer architectures and electronic interfaces which could support ITS safety products deployment. The second thrust invovled historical research into crashes.

Programs are under development for the third thrust to develop specifications for countermeasures against collisions during lane changes, merging, backing intersection and roadway departure. A study is also underway to develop a specification for a degraded/drowsy driver alert warning sensor. Cooperative research in ongoing with universities and industry to support the development of commercially acceptable sensors which support forward crash avoidance, automatic braking for heavy trucks, optical lane detectors, intelligent cruise controllers, and automatic emergency medical notification following a serious collision.

The NADS will also be available for research by academic institutions, medical researchers or the automotive/transportation products industry. Since traffic management and traffic information systems are now becoming an integral part of our transportation infrastructure, it is appropriate to research the impact of potential new highway and intelligent in-vehicle information and control systems on the typical driver to resolve any human factors issues before large scale implementation.

NADS Mission

The NADS will provide a world-class driving simulator with the following capabilities: (4)

1. ***A research tool to conductfundamental studies into the operation of the complex driver-vehicle-environment system. The most valid method of studying* driver *behavior is to make direct observations while the driver is engaged in the driving task in a real vehicle on the highway. However, rhis may expose the driver to unacceptable safety risks.***

2. ***A powerful and cost effective tool for conducting highway engineering and design research related to traffic safety Researchers will be able to evaluate alternative designs for intersections. traffic control devices, and* highway *signing without incurring the prohibitive cost of construction.***

3. ***A means to study driver crash avoidance behavior and related accident reconstruction. The complete control of highway environment and traffic scenarios provided by the NADS will allow researchers to set up hazardous situations and measure driver response.***

4. ***The capability for safely evaluating advanced vehicle communication, navigation, and control technologies which are now being developed as part of the Intelligent Transportation Systems program. important questions regarding the effect of these systems on driver workload. attention. behavior and overall safety need to be addressed during their development. It is imperative to determine beforehand whether any of these advanced systems will have an unintended or detrimental impact on driver performance or highway safety.***

Since the vehicle and driving environment are under the control of the simulator programmer, researchers will be able to evaluate complex dnver-vehicle-information systems interactions with repeatable experiments.

History of the NADS Development

Driving simulators have been used for basic research since the 1960's since they offer:

- Controlled experimental conditions and tasks;
- Experimental repeatability and events observability;
- Ease of experiment change through parameters or scenarios;
- Schedule, cost efficiencies compared to highway or proving ground experiments;
- Safety to the driver.

An excellent review of the characteristics and limitations of 20 different driving simulators is found **in** Weir and Clark's paper.(l) During the 1970s and 1980s federal and state officials became concerned about the accident rate in the U.S. When it was found that 60-80s of all accidents are attributable to human factors (2), the question became: could simulator technology be used to better understand the causes and conditions leading **to** accidents? By 1988, NHTSA began to seriously examine the potential for a high-fidelity simulator to be used as a national asset for driving research. Together with the University of Iowa Cooperative Research Center for Simulation and Design, an initial feasibility study and design concept was completed in March 1990.(1) This study reviewed the evolution of operator-in-the-loop, "'real-time" simulators based on the technology used to develop systems for training pilots and astronauts. The highest fidelity simulator reviewed was the NASA Ames Research Center's Vertical Motion Simulator (VMS) used both to train Space Shuttle pilots and to evaluate the design of advanced aircraft control systems from a human factors viewpoint.(,) The VMS was configured as a driving simulator with appropriate scenery and control interfaces which led to one key finding: the perceived realism of driving maneuvers was enhanced with large translational travel (greater than five meters) over smaller one meter translations available with a typical flight simulator.

A high fidelity Daimler-Benz driving simulator in Berlin was developed in the 1980s based on known aircraft simulator technology and has been used to evaluate: four-wheel steering, active suspension, roll control, electric power steering, warning systems, driver information systems, accident reconstruction. and driver maneuver responses to panic situations.(7) The horizontal motion was originally limited to one meter, but Daimler-Benz has upgraded the simulator with a new visual display system and a major motion system modification providing lateral movement up to $\pm$ 3.8 meters.(8)

Several other driving simulators presently exist or are under development. Among these are fixed-base research simulators at Ford, General Motors, Chrysler, and Mitsubishi. In addition to Daimler-Benz, simulators with motion cues include: the IDS at the University of Iowa: a simulator at Dynamic Research, Inc.; the VTI simulator for the Swedish Road and Transport Research Institution: and INRETS, an advanced simulator under development by Thomson CSF.

To reproduce real-world cues in an advanced driving simulator the architecture must provide:

- Wide angle, high resolution visual displays, updated at more than 60 Hz, with transport delays on the order of 50 msec.;
  Rich. high density, visual scenes normally encountered in traffic;
- A large motion capability to generate the sustained lateral and longitudinal cues experienced during acceleration, braking, lane changes, exit ramp turns, etc; (9)
- Near unity gain in the motion system for transient maneuvers such as lane changes and high motion gain cuing for sustained maneuvers such as exit ramp turns;
- High frequency vibrational response to 50 Hz to provide "road feel" cues;
- Tight temporal correspondence between visual, motion and audio cues;
- Minimal adverse/spurious cues from artifacts related to limited motion travel;
- A high-fidelity audio environment for road and vehicle sounds
- An actual car interior with primary control systems (steering wheel, brakes. accelerator) providing the proper control response and feedback: and
- High-fidelity vehicle dynamics models.

In September and November of 1991, NHTSA released the NADS Requirements Study.(m) Volume I examined the potential user, categorized research level fidelity requirements and examined potential ITS research applications. including:

1. Assessing the impact of advanced technology-on a driver's performance, workload and safety.

2. Evaluating warning systems for collision avoidance, lane deviations, etc. A primary objective would be to evaluate these warning systems in a safe, but stressful scenario (e.g. with heavily fatigued drivers).

3. Evaluating the human factors problems associated with in-vehicle information systems for navigation, route guidance and automatic traveler information systems. Safety and workload implications would be evaluated when developing product guidelines.

4. Evaluating driver use and acceptance of automatic vehicle control systems for headway control and lateral lane positioning. This research would focus on the typical driver's ability to enter and exit automatic mode operations such as platoons or special headways.

This last objective is closely connected to the Variable Dynamics Testbed Vehicle, another program underway with NHTSA and JPL to develop a roadworthy vehicle with software controlled dynamic performance of steering, braking, throttle and driver feedback together with active to semi-active suspension automatic braking to investigate driver response to such systems and their value in crash avoidance.(u) The VDTV and NADS will jointly explore crash avoidance technology. The simulator fidelity requirements for these research topics are shown in Table 1; as currently envisioned. NADS is planned to have "high fidelity" in all areas. Of significant concern to potential users was the hourly operating costs charged to conduct research on the simulator with most respondents sensitive to costs over $1,000/hr for a high fidelity simulator. (11)

While NHTSA was gathering design requirements for the NADS, it was also conducting a competition for a research site to house and operate the NADS. In January 1992, the University of Iowa was selected over five other potential university sites as the home for the NADS. One key selection factors was the investment and effort the University put into vehicle simulation and driving simulators. The University of Iowa has developed a powerful set of multi-body vehicle simulation models and developed an interim driving research facility known as the IDS (Iowa Driving Simulator) with lower cost technology. The IDS is now fully functional and supporting research.(13)

Meanwhile, NHTSA prepared a detailed functional specification document and planned a two phase acquisition strategy for the NADS. In the first phase, two $1.35 million contracts were awarded for a 13 month (2/94 to 2/95) competitive Svstem Design ending in a NADS Preliminary Design Review. The two contractor teams in Phase I were led by TRR' in Redondo Beach. CA and Contraves in Tampa. FL. Phase II, System Development. was awarded to the TRW team in February 1996 to design, develop. and install the world's highest fidelity driving simulator. The TRW NADS team consists of:

- TRW Systems Integration Group as system integrator and operator/researcher stations developer;
- MTS Systems for all aspects of the motion system including motion control;
- Evans & Sutherland for the computer image generators, dome, projection display system, and initial visual databases:
- Dynamic Research. Inc. for developing four cabs. associated control interfaces, and integrated systems development support.
- I*SIM, for the in-cab audio system and audio databases.

NADS Technical Requirements

The TRW team's design approach. the planned technical performance characteristics for the NADS are shown in Table 2.(14) These performance capabilities were selected to satisfycritical design requirements. The key design features include:

- High fidelity, multi-modal cueing temporally correlated to within + 28 msec.,
- 300 by 40 degree visual display field-of-view with ultra-high resolution insets,
- Large scale (± 10 m). high bandwidth (10 Hz) translational motion,
- Adaptive motion drive algorithms with rate limited tilt coordination.

This design provides an extremely realistic cuing environment with high motion recovery (nearly one-to-one correspondence with real world cues) for nominal driving maneuvers.

NADS ARCHITECTURE

The NADS system employs a modular architecture (Figure 1) consisting of a series Df subsystems which provide each primary cueing function, a simulator monitor and control (SMAC) function, or other essential support functions. High fidelity sensory cues are provided by the Motion, Visual, Aural, and Cab and Control Feel subsystems. SMAC subsystems perform the functions necessary for the simulator controller and the researcher to safely monitor and control all aspects of the simulator and the ongoing experiment SMAC subsystems include the Simulator Operator station (SimOP), Researcher Interface Module (RIM), System Control and Safety Monitor (SCASM) and the Power Control Unit (PCU).

The NADS subsystems are linked together via a real-time communications network designed to have high bandwidth yet minimize data latency, thus providing cue synchronicity. There are two real-time data communications networks. The first handles real-time control and cueing, while the second is dedicated to collecting all the data and storing it for off-line analysis. A third, non-real-time network. facilitates the downloading of runtime software and databases to the various subsystems. This system architecture includes hardware discretes within the SMAC and cueing subsystems to initiate an emergency stop or system aborts in the event of a hazardous or out-of-bounds situation.

The multi-processor architecture, real-time executive and dual real-time data communications networks were selected to support the following design goals:

- Deterministic, synchronous delivery of cueing commands with minimum latency,
- Distributed processing to minimize processor-to-net data transfer bottlenecks,
- Large data handling capacity for monitoring simulator systems and driver task perfomiance, archival data and virtual prototyping .

Motion Subsystem

The NADS motion system (Figure 2), provides the low-, mid- and high-frequency motion cues to the driver. The largest portion is an X-Y platform featuring a steel belt drive system providing up to 400 square meters of allowable movement to provide ***sustained,*** low frequency motion cues. The use of servo motor driven steel belts minimizes backlash, noise and unwanted vibration. This large X-Y platform also allows the use of smaller tilt coordination (washout control) which invariably produces false cues in smaller, standard simulators.

Riding atop the X-Y platform is a custom hexapod which provides the mid-frequency cues through 1.2 meter stroke hydraulic actuators. On top of the hexapod is the platform holding the vehicle, the visual display subsystem and the yaw turntable. The yaw turntable. capable of $\pm$ 330 degrees is also driven by a steel belt mechanism. High frequency, short stroke, hydraulic vibration actuators mounted to the vehicle chassis give the driver a sense of "road feel." These actuators are dynamically isolated from the rest of the platform via active cancellation which minimizes vibrations to the dome structure. Motion control algorithms feature both linear and angular adaptive logic to minimize washout when the simulator is not near a physical boundary.

Visual Subsystem

The visual system (Figure 3) is planned to incorporate the most advanced, next-generation multi-channel image generators and display hardware. The system will feature new technology to provide near eye-limited resolution images in the primary forward field of view for drivers which accommodates research on perception of detail for signs and other vehicular activity. Three rear-view mirror scenes will also be displayed. All driving scenery will feature complex 3-D imagery with fully color textured buildings, pedestrians. and other natural environmental objects. Animation for up to 256 independent objects will be provided to create busv traffic situations. The projectors and cab will be contained in a 24-foot dome of composite material capable of withstanding the accelerations and vibrations of the motion system. Prior **to** actually conducting experiments, the researcher and NADS support staff will determine the scenario and scene content necessary for the research. The NADS staff will then use software engineering environment (SEE) tools to develop the scenario for the experiment.

Cab and Control Feel Subsystems

The proposed four cabs will be derived from actual vehicles; two passenger types, one sports utility, and one truck cab. Both interior and exterior appearance will give the subject the sense of entering a real vehicle. The cabs will feature digital processing systems with fiber optic communications. All unneeded weight (such as the engine and transmission) will be removed, though numerous additional electronics will be added and tucked away inside. High fidelity steering wheel, pedals and transmission shift characteristics are to be provided by digitally controlled. high bandwidth, tunable servo actuators. Cabs will feature the full functionality of Original Equipment Manufacturer (OEM) in-vehicle systems such as secondary controls (turn signals, etc.), instrument displays, together with environmental and entertainment systems. The control logic for the primary controls (steering, brakes, accelerator) will be tunable to allow the simulation of any actual or proposed vehicle response. The cab will also contain audio and video equipment for the researcher to monitor and record the actions of the driver. Reconfigurable dashboards will enable integration of driver communication, navigation systems and other ITS devices.

Audio Subsystem

The audio system is a high-fidelity digital sound reproduction system which will surround the driver with a natural sound environment. Multiple speakers within the vehicle provide sound cues which are directionally correct and time correlated with the scenario to enhance driving sensation realism. Normal engine. vehicle and environmental aural cues as well as special sound effects such as tar strips, tire blowout, or a tire-off-the-pavement effect are planned..

Math Models and Simulator Control

The mathematical models governing the vehicle simulation and the simulator executive control are planned to be derived from the University of Iowa's NADSDYNA and CORE software packages currently in use on the Iowa Driving Simulator NADSDYNA is a collection of automotive vehicle models wrapped around a high fidelity multi-body dynamics formulation known as Real-Time Recursive Dynamics (RTRD). This package of over 20,000 lines of FORTRAN code provide the multi-body constraint. powertrain, brake. steering and aerodynamic forces used to simulate the vehicle. The CORE software provides schedulin,. data control, scenario control and user interfaces for operating the simulator and initiating the simulation. Provision is being made in the architecture for incorporating other user-provided vehicle dynamics models, or interfaces to new on-board driver information electronics.

The facility will also include a software engineering environment for developing experimental scenarios, and special databases (visual, audio, roadways), modifying vehicle models for specific research, and for experimental data collection. reduction and analysis.

Safety and Data Collection

Ensuring safety of the test subject is paramount, Each cueing subsystem contains its own safety monitoring functions to prevent injury to the driver in case of malfunction. On top of these safety features, the NADS incorporates an independent fully redundant safety monitoring system within the System Control and Safety Monitoring function (SCASM). The SCASM prevents activation of the simulator "run" mode if any potentially hazardous situation exists, such as: safety belt not fastened, perimeter bay doors open. or any subsystem not reporting good status. The SCASM can initiate a system abort if it detects any anomalous behavior. such as loss of communications with a subsystem, or out-of-range forces being requested or applied to any motion-drive actuators. In the event of extreme emergency, the SCASM can disconnect power to the subsystem via a direct interface to the power control unit. As an additional. final safety feature, system emergency stop initiators are available within the cab. at the Simulator Operator station. and within the simulator high-bay.

The cab will contain several video camera and a voice communication system to record driver actions with provisions also collect physiological data. All scenario and run-time dynamic data will be available to the researcher for collection and later analysis. In real time the researcher can also define derived parameters such as following distance or lane deviations and have statistics collected and presented at his station.

PROGRAM PLAN AND CONCEPT OF OPERATIONS

The present NADS program plan outlines a 39 month development effort for the NADS. Critical Design Review is scheduled for early 1997 with installation and integration at the University of Iowa occurring in 1998. Initial research operating capability for the simulator is scheduled for 1999.

In order to function as a national asset for research, NHTSA and the University of Iowa will establish a mechanism for defining and scheduling research time on the simulator. Experienced software and visual display engineers will work with the researchers in advance of their scheduled experiments to:

- Prepare a detailed experimental plan,

- Define the scenario,
- Plan software model changes if necessary, or include experimenter supplied models,
- Plan for data collection and reduction.
- Plan for the recruiting and preparation of test subjects.

In addition to the main NADS simulator. the facility will have a Simulation Development Module (SDM) for experiment checkout prior to hosting everything on the NADS itself. The SDM is a low cost means of setting up and tuning the experiment prior to using the NADS. It will include one of the four cabs, and a lower fidelity visual display system. The SDM is planned to include a simulation of the motion subsystem to investigate the potential demands on the actuators due to the planned scenario and maneuvers.

All software and databases developed specifically for an experiment will be protected and kept isolated from other researchers. Data security will be provided to ensure proprietary rights are protected. Before actually conducting an experiment on the NADS, the NADS staff and researcher will check out the scenario and expected data flow in the SDM. Test subjects will be notified and scheduled. Finally, a cab will be configured on the NADS and all software files and databases will be hosted ready for the experiment. A library of generic scenarios and city/rural databases will be maintained to allow research in areas not requiring unique databases.

The simulator operator (SimOp) and the guest researcher will each have their own stations with multiple interactive monitors allowing each to select, monitor and record numerous experimental parameters. The SimOp has system control and safety monitoring responsibility, and will serve as an expert on the simulator to assist the researcher in preparing the scenario and scripting the files and events. Prior to conducting experiments the SimOP will run a Daily Operational Readiness Test to ensure all systems are safe and ready for use. The researcher will be able to pre-define a set of derived performance parameters such as headway, closure rate, mean lane deviations, etc. which can be collected and displayed. The researcher will also have control of “special events” which can be inserted into the simulation at his/her discretion. These include the actions of other drivers. system failures, or ATIS messages going to the driver.

During an experiment the SimOP and Researcher will be in voice contact with each other and the subject driver. The researcher will have several monitors for viewing the displayed visual scene, and observing the actions of the driver via the cab video cameras. Following the experiment the NADS staff will assist with data reduction and analysis, depending on the researcher’s needs.

APPLICATION TO ITS AND AHS RESEARCH

The use of a very high fidelity driving simulator provides AHS and ITS component manufacturers with a cost effective and safe opportunity to develop, test and validate ITS concepts, products and functions. It also provides an excellent means to gauge user acceptance of various ITS applications both m-vehicle and within the roadway/roadside infrastructure. The NADS allows modeling and testing of ITS designs while these technologies are still in the conceptual or early development stages. The simulator offers a low risk approach to fine tune designs and shorten the market introduction time while ensuring the human interface is well understood.

There are any number of ways to categorize ITS studies and evaluations using the NADS. This discussion considers one approach by using three main categories: (1) Human Factors Studies, (2) Product Evaluations and (3) Safety Studies. Research topics within these major categories will often overlap, as will the resultant study data, but the emphasis within the categories is relatively straightforward. The real benefit of the NADS is the repeatability of the tests and the ability to control the perturbations of specific test scenarios. Also, with the tremendous amount of data that can be collected, it is anticipated that test results from one category could be used by scientists conducting studies in other categories

Human Factors Studies

Tomorrow’s cars and trucks are envisioned to have integrated display in support of the Automated Highway System. These on-board systems need to be thoroughly evaluated for the human factors impacts. Driver acceptance of transportation-related information or automated control systems and the resultant actions taken must become an important field of research. Human factor studies will address the interaction of the vehicle operator with the automated information systems and data the driver must process as he/she drives under all roadway conditions (urban. rural, expressway, day, night, congested, free-flowing. etc.).

One recent study conducted two experiments using the existing Iowa Driving Simulator specifically to explore human factors issues relating to projected AHS capability.(l4) The first experiment used 36 drivers between the ages of 35 and 34 in a simulation with one lane (the leftmost) of a freeway reserved for automated vehicles with no transition lane. The second experiment used 24 older drivers (over 65) in the same scenario, Initial results showed dependencies on the control transition which adversely impacted following automated traffic to be a function of experience (previous trials) and overall traffic velocity, but not age.(15) The IDS showed itself to be an efficient means of conducting a large number of experimental runs in a short time and obtaining useful statistical results.

Driver information overload situations can occur because of ITS-added functionality. How should the driver interact with the on-board technology? Where is the best location of an on-board system requiring driver interaction, what qualifies as good data interface, what are the ergonomics of the device ? These questions need to be examined safety with the driver under a realistic driving load -- not at a workstation terminal with an incomplete environment or little situational stress.

Human reactions to various methods of information delivery need to be evaluated under stress conditions. What is the proper format? Are there regional or language barriers? How can a developer minimize the information flow to the truly essential? How can the system be integrated into the rest of the vehicles information systems? We should not repeat the mistakes of the past when. as digital technology was taking off, aircraft cockpits became overloaded with continuous. non-integrated information displays.

Product Development and Evaluation

The NADS will offer a safe and methodical tool for the analysis of ITS products both for the infrastructure and the vehicle. These products can be installed in the vehicle and stimulated with proper signals to provide the same information planned in the real world. For example, various implementations of automated collision avoidance. or multiple vehicle platooning control laws can be simulated and evaluated under realistic traffic scenarios.

The NADS will support detailed evaluation and acceptance testing of Automated Vehicle Control Systems (AVCS). As already shown it will support evaluation of human reactions during the critical transition phases: when the system takes control from the driver, or when the driver regains control from the system. Finally, the NADS can help researchers understand system and human interaction during emergency situations to help modify product designs before they are introduced.

Safety Studies

Safety studies will be closely related to both the human factors and product studies, but will more likely be performed by the safety community to address specific issues of Intelligent Transportation Systems. Prior to marketing a new in-vehicle system, safety studies should examine how ITS-related information will dilute the driver’s concentration from basic driving activities. This applies to both on-board as well as infrastructure delivered information. For example, how long is a driver’s attention diverted by an ITS product interaction? What are the impacts of multi-channel monitoring? What typical actions or reactions do drivers make to unfamiliar automated vehicle control actions? Potential evaluations could done of on-board ITS components that enhance collision avoidance by responding faster than a human to impending dangerous situations. These studies involve a multi-sensor analysis of speed, proximity, approach vectors. warning indicators, control actuators, automatic braking. steering, etc. Additional studies on sleep sensors and corresponding alert devices can be done with realistic fidelity.

CONCLUSION

This paper has described how the National Advanced Driving Simulator can be a powerful research tool available to ITS engineers, product developers, and regional traffic engineers who have a need to know the impact of

ITS technology on the driver. The development of the simulator will take three years: but as the world's most sophisticated driving simulator, NADS will help provide research answers that would be difficult, costly and often unsafe to obtain under actual roadway driving conditions. The level of sophistication within the NADS is planned to meet the fidelity and flexibility requirements of system level ITS research. The NADS offers easy experiment setup, product integration, and data collection. The level of fidelity will allow researchers to implement practically any experiment that they would consider in a real vehicle, on any roadway. As NHTSA'S largest research and development program, NADS will set a new tone for cooperation with academia and industry for the public good.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Keith Brewer, NHTSA's NADS program manager, Professor Ed Haug from the University of Iowa, Dave Weir from Dynamic Research, Inc., and Fred Tsuchiya from MTS Systems for their review and critique of this paper.

REFERENCES

I. Aerospace Daily, "DOT to Launch IO-year Transportation Infrastructure Upgrade" Secretary Pena address to Transportation Research Board, l/l l/96.

2. Haug. E.J.. et al "Feasibility Study and Conceptual Design of a National Advanced Driving Simulator". DOT HS 807 596, NHTSA, March 1990.

3. Federal Report, U.S. Department of Transportation, ITS America Coordinating Council Meeting, July 1995.

4. NHTSA. "National Advanced Driving Simulator Functional Specification Document". NHTSA, July 1993.

5. Weir, D.H. and A. Clark., "A Survey of Mid-Level Driving Simulators", SAE paper 950172, March 1995.

6. Danel, G.L., "Vertical Motion Simulator Guide", NASA Technical Memorandum 103923, 1993.

7. Hahn, S. and W. Kaeding. "The Daimler-Benz Driving Simulator - Presentation of Selected Experiments," SAE paper 880058. 1988.

8. Kaeding. W.. and F. Hoffmeyer. "The Advanced Daimler-Benz Driving Simulator", SAE paper 950175, 1995.

9. Garrett, W.R. "Sizing the Motion Base of the National Advanced Driving Simulator", DOT HS 807 979, 1993.

10. Allen, R.W. et al, "National Advanced Driving Simulator Requirements Study, Volume I", DOT HS 807 807, NHTSA, 1991.

11. Weir, D. and R. Heffley, "National Advanced Driving Simulator Requirements Study, Volume II". DOT HS 807 826, NHTSA. 199 1.

12. Marriott, A.T., et al, "VariableDynamic Testbed Vehicle Study, Final Report, Vol II: Technical Results, JPL D-11266, Vol II, NASA/JPL, 1994.

13. "Driving Simulation at the University of Iowa", Center for Computer-Aided Design, University of Iowa, 1994.

14. TRW Inc. "National Advanced Driving Simulator System Development Specification", 1995

15. Bloomfield, J.R., et al, "Human Factors Design of Automated Highway Systems, Experiment #l and #2: the Effects of Design Velocity, Intra-String Gap Size, Traffic Density, and Driver's Age on the Transfer of Control from the Automated Highway System to the Driver", Honeywell Technology Center, (Draft Report, May 1994).

Research Application	**Visual Fidelity**	Motion **Fidelity**	Computation Fidelity	Cab/Control Feel Fidelity	Audio Fidelity
Advanced Technology Impact on driver performance	Medium	High	High	High	Medium
Evaluation of warning Systems	Medium	Medium	High	Medium	High
Safety evaluation of in-vehicle information systems	Medium	Low	Medium	High	High
Evaluation of automatic control svstems (human factors)	High	High	High	High	High

Table 1. NADS Fidelity Requirements for ITS Applications (9)

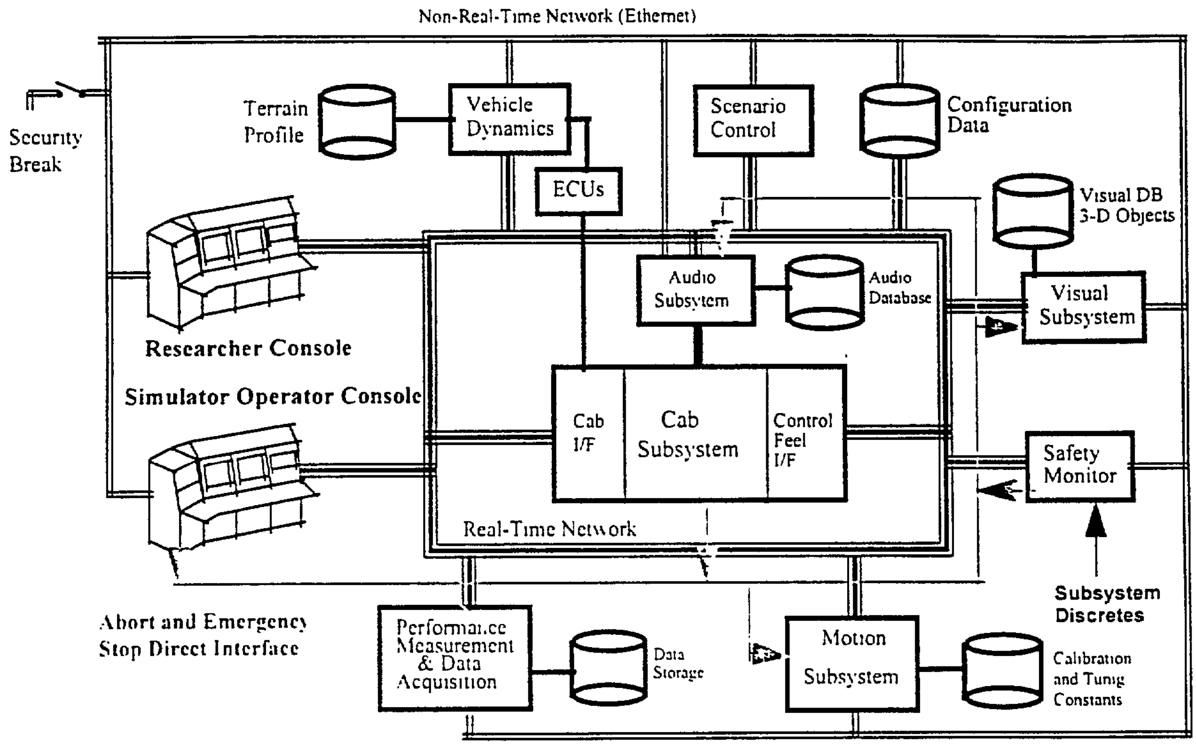

Figure 1. NADS System Architecture

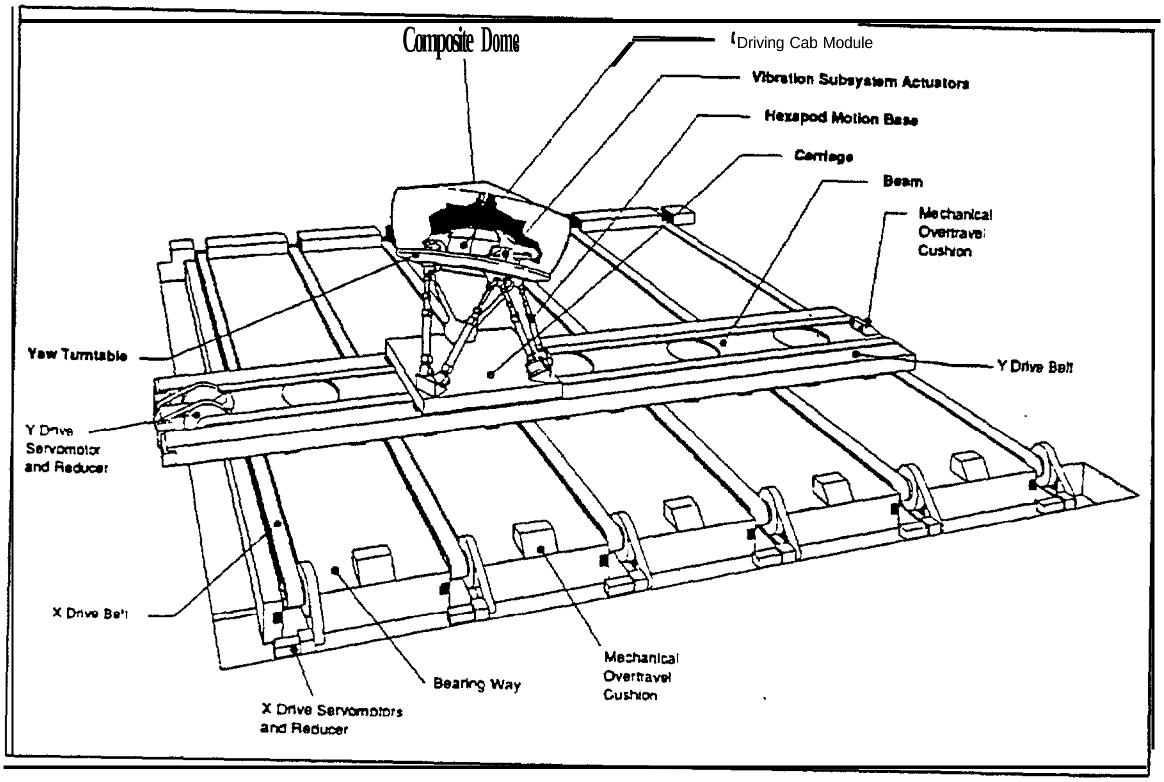

Figure 2. NADS Motion System

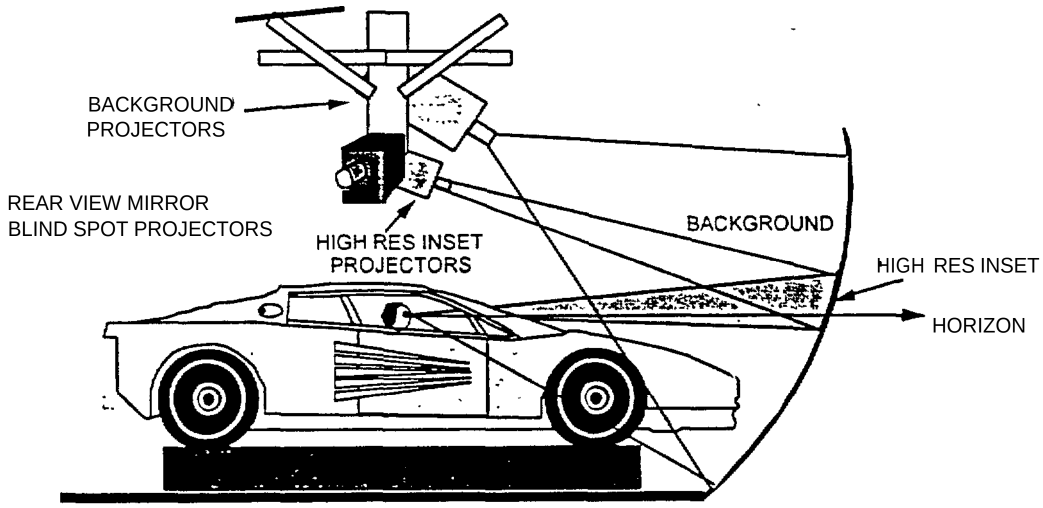

Figure **3. NADS Visual System**

List of Tables and Figures